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Systems thinking research - principles and methodologies to grapple with complex real world problems

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ABSTRACT

Topic *– Systems thinking (see the INCOSE UK Z7 Guide) provides a common language for needs driven process integration. We take the thinking further and present the principles and methodologies used by the Systems Centre to integrate research processes drawn from fields as diverse as physical and social science, engineering, and business management, and use case examples to demonstrate how they can be applied in engineering systems where 'soft' institutional, cultural, people related and process integration barriers can be key drivers of complexity.*

Points *–*

i) From recent work between Research Engineers and practitioners a unifying framework for highly effective systems thinking research has been developed founded on seven principles: purposefulness; balance of breadth and depth; harnessing diversity; clarifying boundaries; building confidence and momentum for change; communicating in the language of stakeholders; and stimulating further learning.

ii) These principles underpin the development and teaching of practically oriented systems research methodologies by the Systems Centre, which allow problems associated with complex real-world systems to be addressed.

iii) Industry partners are the Systems Centre stakeholders and each project undertaken by a Research Engineer is driven by stakeholder needs and guided by these principles and methodologies.

iv) The Systems Centre now has 4 cohorts of Research Engineers comprising a total of 50 research projects with 30 companies covering a wide range of topics including sustainability, process improvement and decision support, safety, and new product development. These all have an emphasis on solving real world systems problems in a rigorous fashion in timescales appropriate to the needs of our industrial partners. Examples will be given to illustrate the approach.

Keywords – Systems Research, Systems Thinking, Systems Engineering, Systems Practice, Holism, Purpose, Stakeholder Needs, Alignment, Research Methods, Pedagogy, Engineering Doctorate.

1. Introduction

Systems Engineering (SE) can be defined as 'Systems Thinking (ST) applied to engineering problems'[1]. ST has an established pedigree and provides a meta-cognitive, interdisciplinary approach to investigate understand and responding to complexity. It is not the purpose of this paper to expand on the differences and application of ST to SE but rather to focus on its application in research. The INCOSE guide *'What is Systems Thinking?'* (Z7) [2] provides a broad outline and we refer readers to that guide.

To understand and intervene in complex engineering problem spaces, ST embraces research paradigms from the social and physical sciences and their different epistemological and philosophical underpinnings. This has been noted as essential by over 50 Research Engineers (REs) investigating a wide spectrum of engineering problems. It is becoming an established pattern for many research journeys to start as a broadly defined 'hard system problem' only to reveal their true complexity later as the hard / soft system boundary becomes the limit to understanding and forward progress.

The Bristol Systems Centre has been established for four years and is funded by industry and ESPRC grant. Its fourfold purposes are:

- **Work with industry to enhance performance.** The Centre creates competitive advantage by collaborating with industry on leading-edge research, delivery of innovative solutions and motivate and develop future leaders.
- **Training future leaders of industry.** Together with the University of Bath the Centre co-hosts 50 EPSRC co-sponsored Industrial Doctorate (IDCs) Students in 30 companies amassing between them over 150 years research in systems.
- **Developing Systems Thinking through research.** The Centre coordinates the University's research in Systems across a wide range of subject areas and industry sectors.
- **Working with academics to develop industrial collaboration.** The Centre supports academics within the University to help build relationships with industry for knowledge exchange, technology transfer, exploration of novel ideas and industrial sponsorship.

Brown (2009)[3] identifies, correctly in our view, the need to ground methodological decisions in wise consideration of the philosophical underpinnings. The Systems Centre has been developing its own thinking and encouraging its students to explore their research philosophy and adopt a rigorous approach to the development of methodology, especially when applying social science based research and this has paid dividends in understanding, quality of output and rigour as advanced by Brown (2009)[3]. However even

under these conditions it was noted that a deeper exploration was needed to understand and overcome barriers to ST-based SE research in companies.

2. Underpinnings

Scientific principles can be described as operating in objective reality and possessing the following characteristics:

- **Universal** – they apply everywhere in the explored universe.
- **Permanent** – they apply at all times.
- **Unalterable** – they cannot be changed by interference of the observer.

In *'Creating Systems that work'*[4] the Royal Academy of Engineering set forth a set of 'principles' for systems engineering. These 'principles' are social constructs used to guide and enhance human interaction to achieve purposeful ends. In these social constructs, where an interpretive approach is used objective reality is not a notion that applies. Therefore the definition of the 'principle' may usefully be altered to include:

- **Self-evident** – they are known to be true by common understanding.
- **Natural** – they generally emerge without direct consideration or intervention.
- **Independent** – they generally operate whether we value them or not.

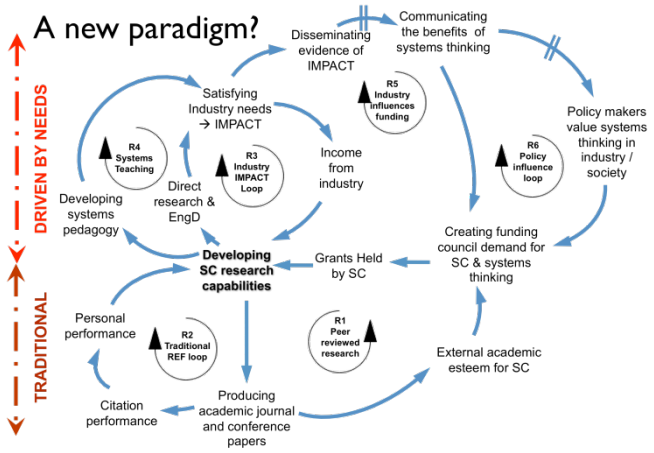
Stevens etal[5] assert that 'systems engineering is about creating effective solutions to problems and managing the technical complexity of the resulting developments'. The RAE principles take this view and focus their principles on addressing the challenges of increasing complexity to achieve purposeful ends.

Systems engineering research impacts the final solution and its final achievement. Valuable research activity should not confirm itself to to a 'business as usual' outcome. Instead, according to Henshaw *etal*[7] the researcher's role is to:

- Conduct research in the context of real engineering problems;
- Exploit their findings through skills development, new processes, templates or enhancement of the systems engineering 'toolkit'
- Express the problem as a generic type (or class) so the outputs have generic applicability.

They go on to assert that it is the role of the systems engineer to take the findings of SE research and apply it to the specific problems at hand not that of the researcher.

This purposeful, impactful view of research yields implications for the way that research, societal and industrial communities may benefit from research activity as the diagram shows.



Traditionally, research activity has been assessed by such factors as citations, peer esteem, conference and paper performance criteria. In contrast, the purposeful view put forward earlier explores impact in terms of:

- Developing the 'systems thinking' pedagogy – leading to greater understanding and education of researchers and practitioners.
- Direct impact through the context of real engineering problems.
- Development of the engineering 'toolkit' for wider communication and impact release.

To enable reliable foundations for these benefits to be accrued a strong platform of 'systems engineering research principles' needs to be applied. This is a gap which the Bristol Systems Centre has been exploring.

3. Closing the gap

The research was conducted by the authors and took place at a workshop held in February 2010 conducted at the Bristol systems centre, comprising researchers, academics, company sponsors and consultants. . Due to the small population (circa 70), the research aimed to provide the beginnings of a generic theory, that can be developed, tested and validated as work progresses.

A qualitative interviewing research methodology was selected as it was accessible to the authors, could be applied to the setting, and, would deliver the results required. The research is aligned ethnographic interpretive approach which seeks to analyse naturally occurring talk and social interaction[7]. Ethnographic studies focus on local derived meanings and the settings within which social interaction constitutes the practical realities of the situation. This approaches consider the content of the talk in the relation to local understanding, and produces data that is highly descriptive of everyday life, including conversational extracts of the environment and ethnographic accounts of interaction.

Ethnomethodological research can be divided into two forms of implementation; the first focuses on the interactive meanings, the second focuses on the structure of the talk. This research focussed on the content and interactive meanings, and placed constraints on the structure. This approach ensured that the environmental effects were reduced to a minimum, structural interpretation was removed

and content and meaning was analysed as the main contributor of expression.

This mixed group was asked to identify the answers to three questions:

1. What are the requirements for success in systems-thinking research?
2. What are obstructions to success in systems-thinking research?
3. What are the principles that apply to 'systems thinking' research so that it makes a difference?

The specific process used was derived from the work of Isaksen *etal*[8] who established Creative Problem Solving (CPS) methods for use in group settings and developed ways to enhance creative productivity by application of a rigorous, flexible language, methodology and toolset. In particular, they describe approaches to frame problems and guide responses to ensure they are specifically directed to the question at hand. In this particular workshop their method argues for the use of 'stems' as powerful language to guide response. Such devices were used to considerable benefit in time and quality of outcome.

The results from the workshop were analysed using Straussian Grounded Theory by which the results were coded, using key words and applying constant comparison techniques to build up a series of 'concepts' that gave rise to seven principles[9]. The volume of data sets was insufficient to justify analysis by computer assisted techniques, such as NVivo.

4. The seven principles

From this analysis the following seven principles emerged and have subsequently tested using the active research projects and experience of over 50 systems engineering researchers at the Systems Centre. Systems research is:

1. Is purposeful

- Systems thinking research involves the creative and persistent pursuit of purpose and clarity
- It recognises that it is tackling 'wicked and messy' problems and that there are high-levels of uncertainty and ambiguity, especially at the outset and that the object of the research is only realised once it is achieved.
- It recognises that purpose and need are in the 'eye of the beholder' manages and measures perception and unifies differing perspectives without diminishing any of them.
- Systems thinking researchers know that to struggle with the problem space and to continuously seek to define and clarify purpose is itself part of the research and journey of discovery.
- It defines purpose in terms of academic, industrial and societal stakeholder needs, specified project outcomes, and pursues these with vigour and rigour.
- Builds people's understanding of the value of systems thinking

2. Balances depth and breadth

- Systems thinking research leverages the best and most appropriate research tradition from social sciences, pure natural and applied engineering and physical sciences, organisational business and management; using the most appropriate method in the most rigorous, systematic way.
- Balances real world demands and academic rigour; creative and critical thinking; past, current and future; hard and soft systems perspectives to create new richer pictures of the problem and solution

3. Harnesses diversity

- Highly effective systems thinking research encourages interdisciplinary thinking, unifies perspectives and action by encouraging a holistic perspective and interaction between disciplines and companies
- Holds and welcomes different conceptualisations of the problem / opportunity space and the tension between them
- Uses the power of different cultures, experiences and viewpoints leveraging their interdependencies to create new insights and understanding

4. Clarifies boundaries

- Systems thinking researchers examine and establish legitimate 'domains of enquiry' considering the whole 'problem / opportunity space'
- They establish and define appropriate system boundaries

5. Builds confidence and momentum for change

- Highly effective systems research achieves change and impacts culture
- Within the boundaries and purpose it is responsive and reflexive to changing understandings, perspectives and insights

6. Communicates in the natural language of the audience

- System thinking research communicates complexity and findings in simple clear ways. It uses rich pictures, metaphors and illustrations to make the complex communicable and understandable
- Synthesises diverse and complex information into understandable forms that enable response planning and wise intervention

7. Stimulates further learning

- Is driven by intense curiosity
- Maps and tells its own journey
- Provides a way to think about the future
- Is iterative and loopy.

5. Developing and applying the principles

The Systems Centre's has been examining its portfolio of projects and these principles are exhibited in most of them.

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